Construction of a Femtosecond Pump-Probe Spectroscopy for Thermal Diffusivity Measurement of Superconducting Niobium

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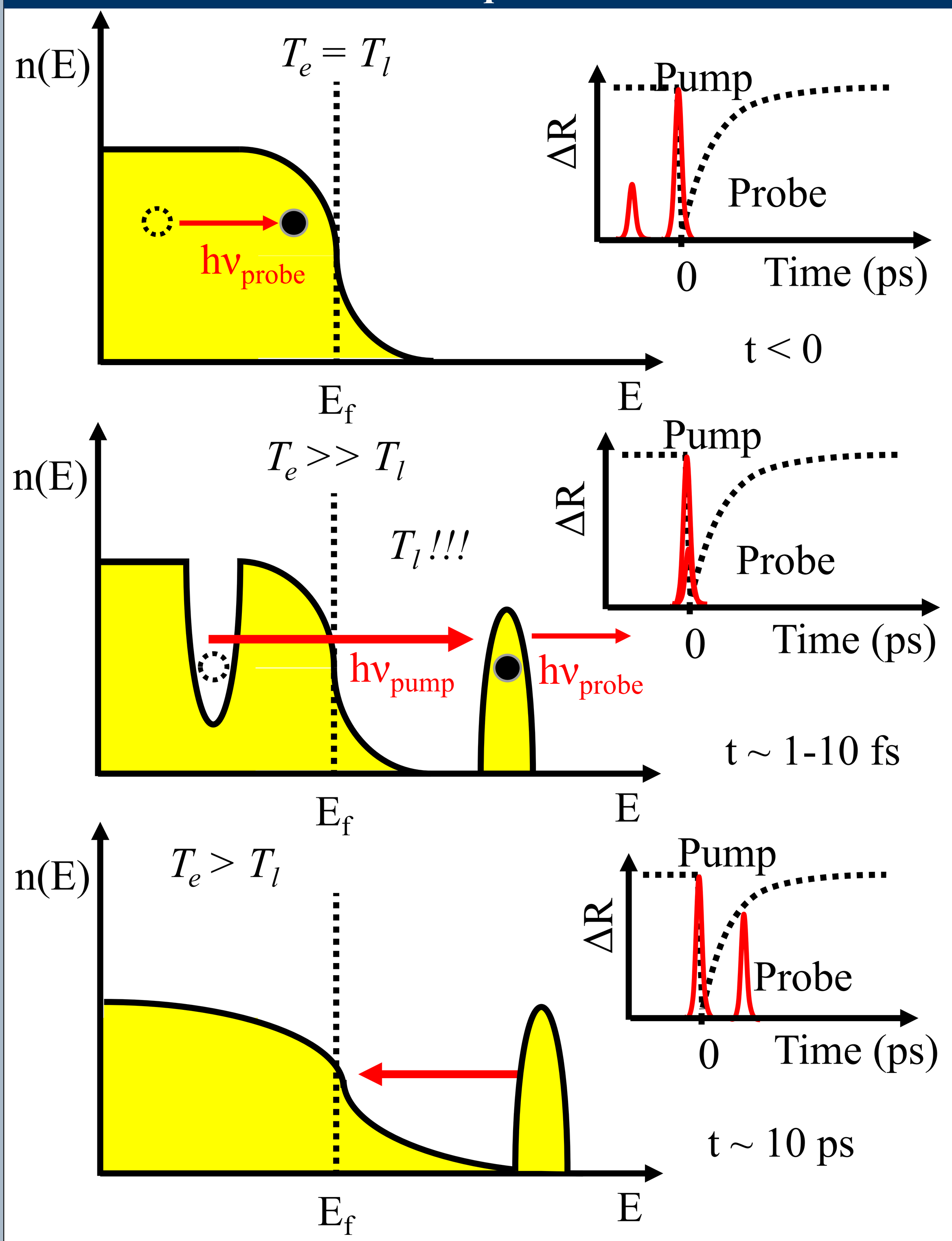
Abstract

- Superconducting Nb is extensively used in particle accelerator application.
- Thermal diffusivity measurement in the nanoscale heat transfer is critical at sub-zero temperature for Nb.
- Experimental investigation of thermal diffusivity measurement of ingot Nb is demonstrated by femtosecond time-resolved pump-probe spectroscopy.
- An optical pump-probe setup is developed using a Titanium: sapphire (Ti:Al_2O_3) femtosecond laser (wavelength = 800 nm, pulse width 100 fs, repetition rate 80 MHz).

Project goal

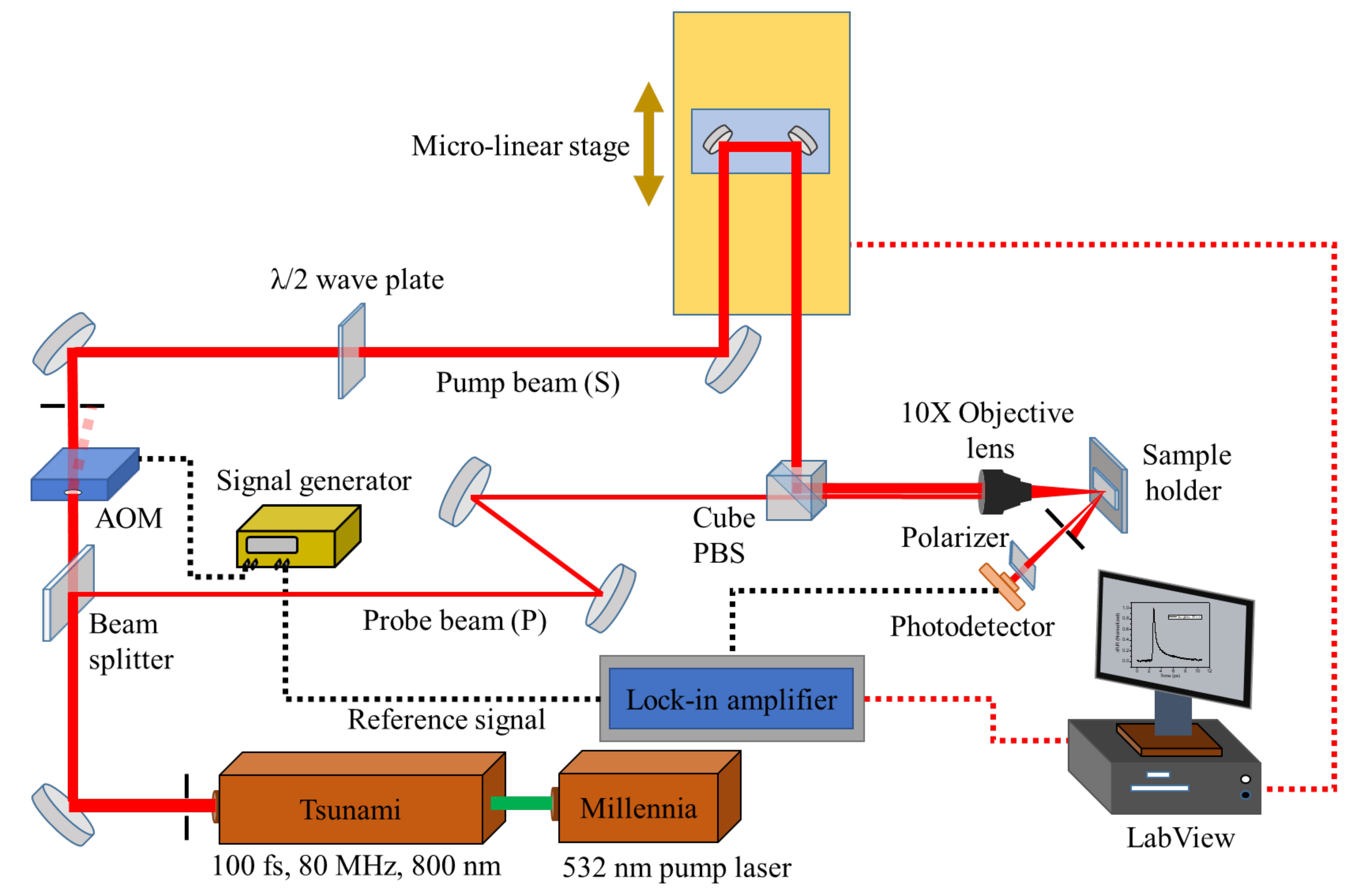
- Measurement of thermal diffusivity of ingot and Nb thin film at critical temperature.
- Investigation of nanoscale heat transfer in Nb thin film as a coating material in particle accelerator.

Generation of nonequilibrium electrons



- Electrons scatter with other electrons on ~1 femtosecond timescales.
- Atomic vibrate takes place with characteristic times of ~1 picosecond.
- Reflectivity is a linear function of temperature and have the same shape as the temperature profile.

Experimental setup



Ti:sapphire femtosecond laser beam is separated into pump and probe beam into 90:10 ratio. The pump is modulated at 1 MHz frequency by acousto-optics-modulator. A lock-in-amplifier is used to detect the thermomodulation in probe signal.

Thermal diffusivity measurement at critical temperature

Thermal diffusivity measurement:

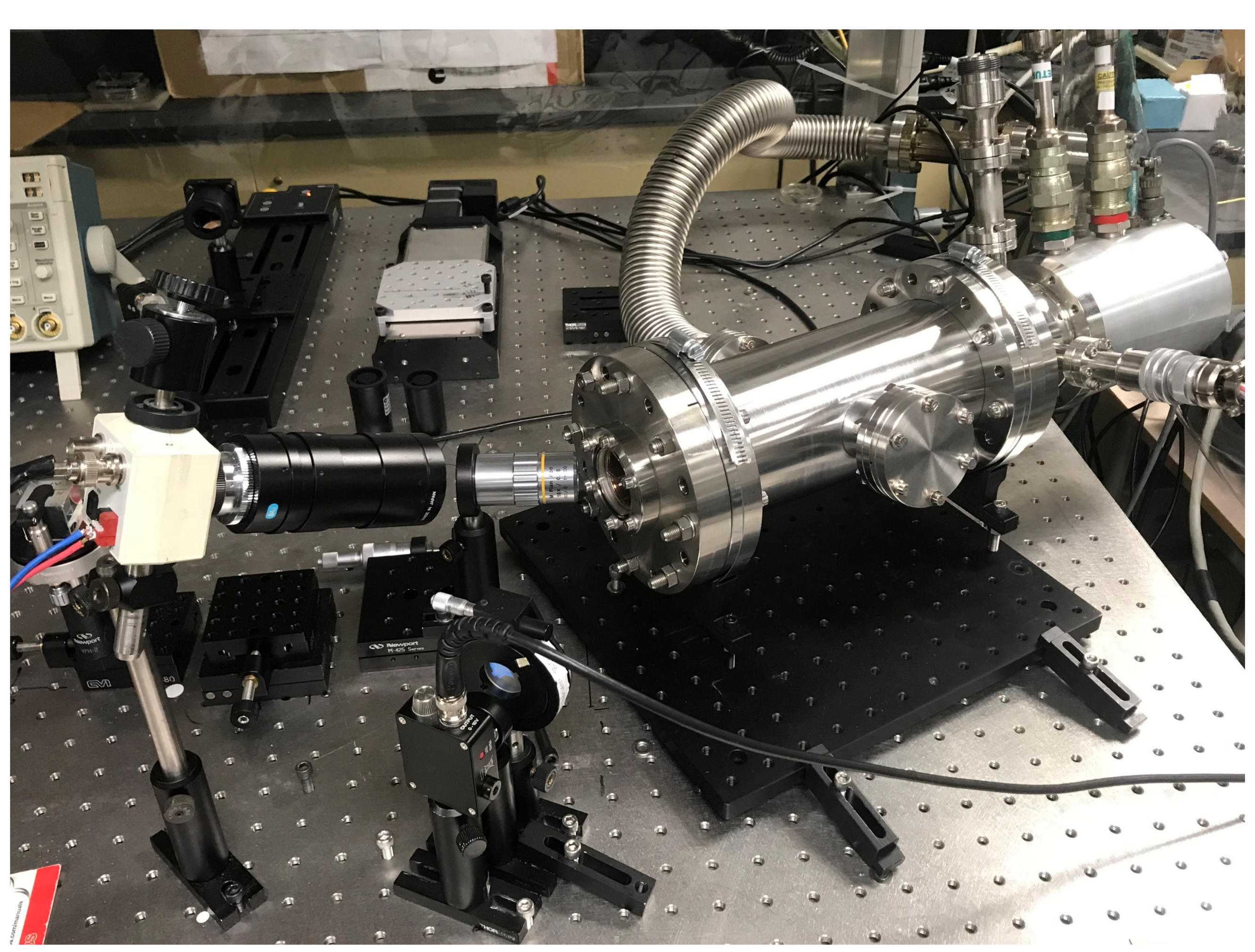
The two-temperature model is a common framework to interpret TTR experiments. The two temperatures refer to T_e the electron temperature and T_l the temperature of the lattice.

$$C_e \frac{\partial T_e}{\partial t} = k_e \frac{\partial^2 T_e}{\partial x^2} - G(T_e - T_l) + S$$

$$S = I(t)A.\alpha.exp(-\alpha z)$$

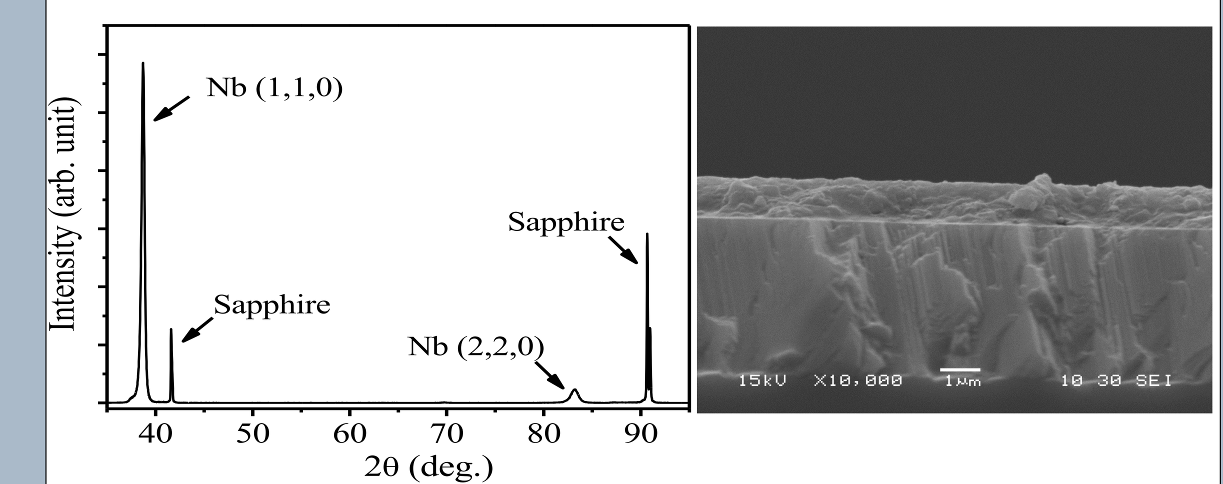
$$C_l \frac{\partial T_l}{\partial t} = G(T_e - T_l)$$

k_e = thermal conductivity (W/m K)
C_e = electron heat capacity (J/m^3 K)
C_l = lattice heat capacity (J/m^3 K)
T_e = electron effective temperature (K)
T_l = lattice effective temperature (K)
G = electron-phonon coupling coefficient (W/m^{3}K)
S = source term
α = the optical penetration depth
Z = film thickness (m)
AI(x,t) = the absorbed fraction of the incident intensity (Wm^{-2})

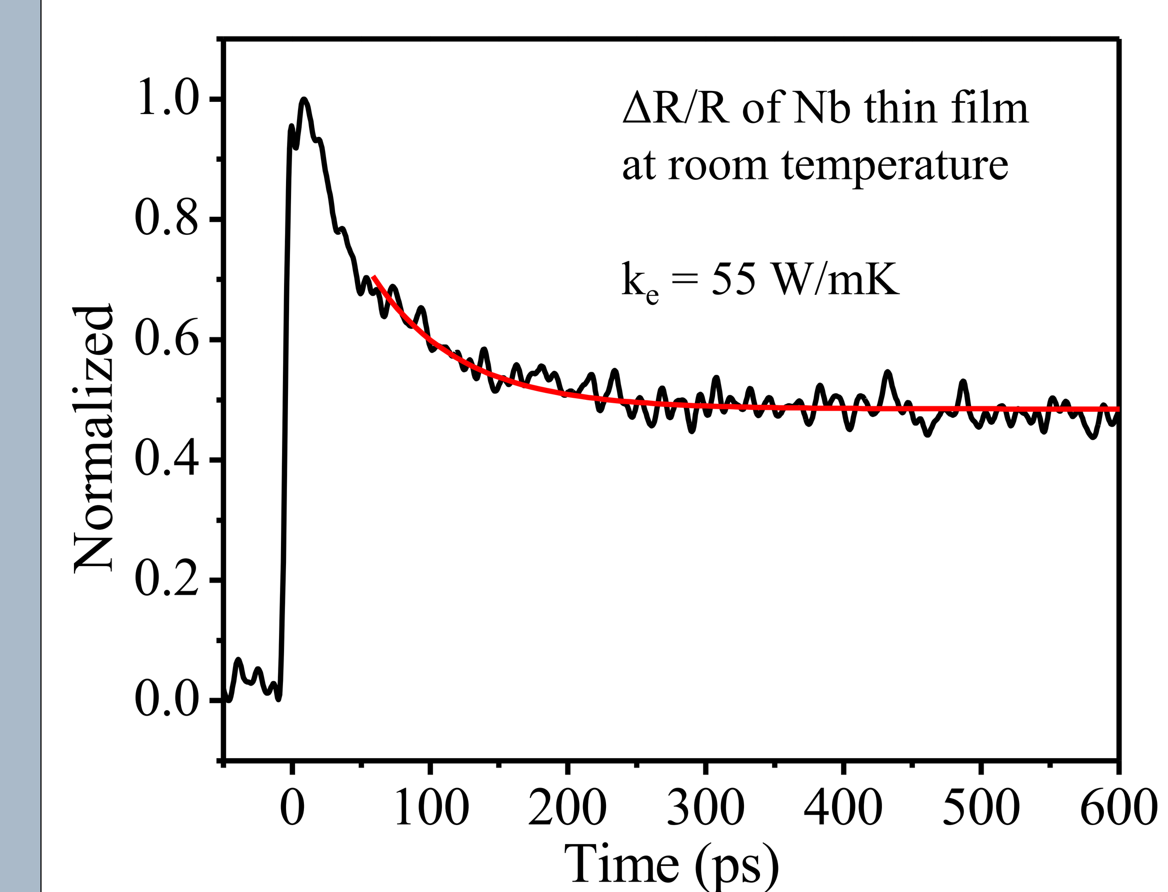


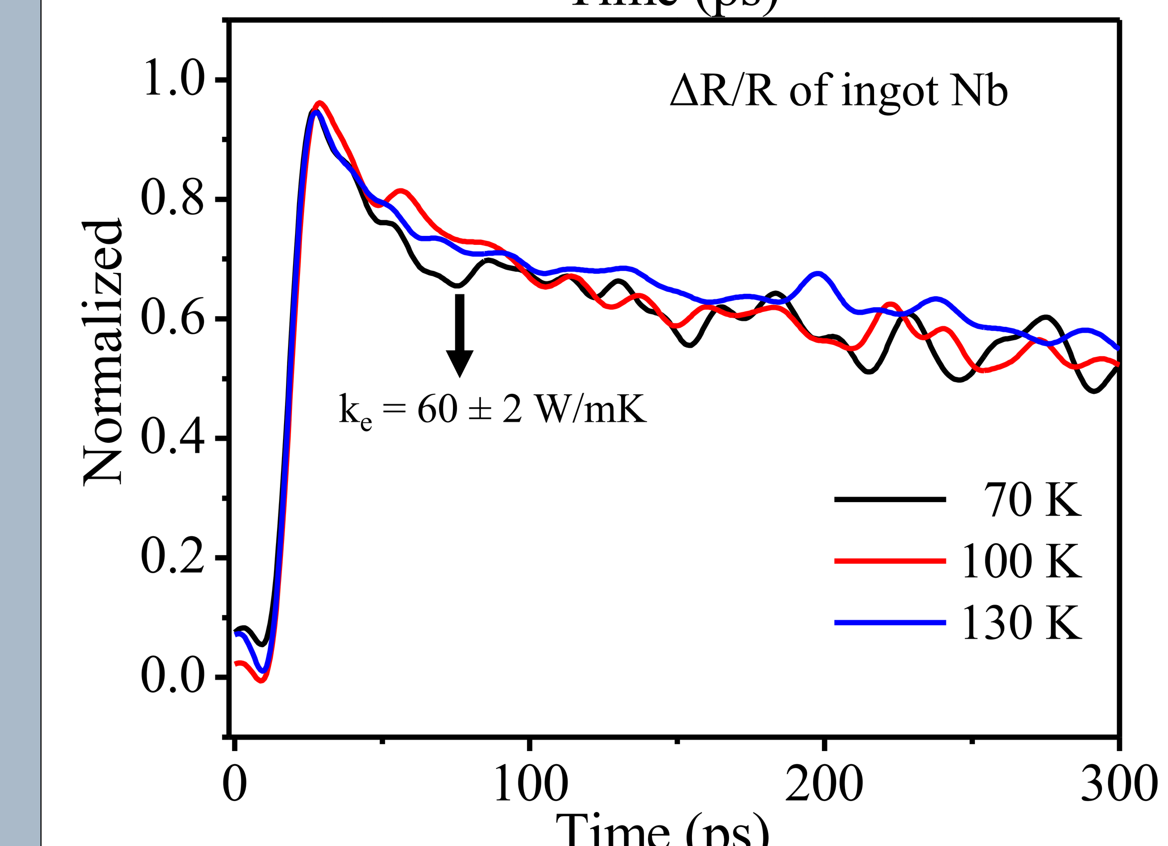
APD cryogenics 10 K system

Results



XRD and SEM of 1μm Nb/Sapphire thin film





Conclusion

Nonequilibrium heating is investigated for Nb with femtosecond pulsed laser. An optical pump-probe technique is used where an femtosecond laser pulse provides the heating event, and the subsequent change in temperature of the sample surface is measured as a function of time.

References

[1] Md. M. Rahman and H.E. Elsayed-Ali, Review of Scientific Instruments, (2019) (submitted).

[2] H.E. Elsayed-Ali, Physical Review B, 43 (1991) 4488-4491.